AGE AND GROWTH OF BIGEYE TUNA (*THUNNUS OBESUS*) IN THE WESTERN INDIAN OCEAN

by

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ABSTRACT. - The age and growth of bigeye tuna (*Thunnus obesus*) from the Western Indian Ocean were investigated using otoliths and first dorsal spines. Microincrements, assumed as daily deposits, were observed on transverse sections of sagittal otoliths from 164 bigeye tuna. The increments were counted to determine age and establish a growth curve. A scanning electron microscope (SEM) was used to count microincrements on fish larger than 100 cm fork length (FL). The von Bertalanffy growth curve is FL = 168.99 (1 - $e^{-0.000879\,(t\,+\,123.38)}$), where FL in cm and *t* in days were used. The fish reaches 59 cm at 1 year, 111 cm at 3 years and 147 cm at 6 years. The use of SEM is required for counting microincrements on otoliths of bigeye tuna over 120 cm. Growth was also studied by analysing marks on the first dorsal spine of 140 fish. The results obtained with spines and otoliths are comparable until 3 years old, but spines are not suitable for larger fish.

RÉSUMÉ. - Étude de la croissance du thon patudo (*Thunnus obesus*) dans l'ouest de l'océan Indien.

L'âge et la croissance du thon patudo (*Thunnus obesus*) de l'ouest de l'océan Indien ont été étudiés avec des techniques de sclérochronologie sur les otolithes et sur la première épine dorsale. Les marques d'accroissement, considérées journalières, ont été observées sur des coupes transversales de sagitta de 164 patudos. Elles ont été comptées pour déterminer l'âge individuel et établir une courbe de croissance. La microscopie électronique à balayage a été employée, sur les individus de plus de 100 cm de longueur à la fourche (FL), pour compter les marques journalières. La fonction de von Bertalanffy est FL = 168,99 (1 - $e^{-0,000879\,(t\,+\,123,38)}$), avec FL en cm et *t* en jours. Les patudos atteignent 59 cm à 1 an, 111 cm à 3 ans et 147 cm à 6 ans. L'utilisation de la microscopie électronique est indispensable pour compter les accroissements journaliers des patudos de plus de 120 cm. La croissance a aussi été étudiée en analysant les marques sur des coupes de la première épine dorsale de 140 individus. Les résultats obtenus à partir des épines et des otolithes sont voisins jusqu'à 3 ans, mais les épines ne sont pas utilisables chez les individus plus âgés.

Key words. - Scombridae - *Thunnus obesus* - Bigeye tuna - ISW - Otolith - Dorsal Spine - Growth.

Bigeye tuna, *Thunnus obesus* (Lowe, 1839), is a large epi- and mesopelagic fish found in all tropical and subtropical oceans. It constitutes an extremely valuable fishery resource intensively exploited by longliner vessels, and purse seiner vessels at various stages of its life cycle. Presently, in the Indian Ocean, purse seine landings of bigeye tuna are essentially composed of small fish (< 90 cm FL) which are immature (Sun *et al*., 1999). Because fishing effort for this species is increasing, there is a need for a suitable method for age determination, for current stock assessments, necessary to ensure effective management of this resource.

A wide variety of ageing techniques have been applied to this species. These include modal length frequency analysis, tagging studies and examination of hard pieces such as scales, vertebrae, first dorsal spine and otoliths (Yukinawa and Yabuta, 1963; Kume and Joseph, 1966; Marcille *et al*., 1978; Gaikov *et al*., 1980; Weber, 1980; Cayré and Diouf, 1984; Draganik and Pelczarski, 1984; Miyabe, 1984; Pereira, 1984; Delgado and Santana, 1986; Pelczarski, 1992; Alves *et al*., 2002; Hampton *et al*., 1998; Lehodey *et al*., 1999; Clear *et al*., 2000; Sun *et al*., 2001). In all these studies, estimated growth rates are relatively high, as generally expected for scombrid fish. However there is considerable variation between studies and no clear-cut data on the shape of the growth curve exist.

In the Indian Ocean a short study was conducted off Madagascar by Marcille and Stéquert (1976) from the catches of pole and line. Tankevich (1982) studied growth using vertebrae and scales. Stéquert and Conand (2000) presented a preliminary study using the first dorsal spine, and otolith microstructure, but the otoliths were only studied with an optical microscope which appeared to be unsuitable for large fish. This study includes the results of the preliminary study. However, this is expanded to include scanning electron microscopy for otoliths of medium size and large fish. The objective is to estimate age and growth of bigeye tuna collected in the Western and Central Indian Ocean.

MATERIAL AND METHODS

Sampling

Pairs of sagital otoliths were collected from more than 600 bigeye tunas, caught in the western part of the Indian

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Ocean during the Regional Tuna Project (1989-1990). Eighty per cent of them were extracted on board French purse seiners based in Mahé (Seychelles) during fishing trips. Others were extracted at Port-Louis tuna cannery (Mauritius) during the thawing of the fish caught by the Mauritian purse seiners. As large bigeye tuna caught by purse seiners are generally uncommon, the landings of longliners based in La Reunion and operating in the southern area of that island were also sampled. From the end of 1999 to mid 2000, eighty pairs of otoliths were collected from bigeye tuna larger than 120 cm.

First dorsal spines were collected from bigeye landed at La Reunion by longliners between September 1998 and November 1999. A total of 140 spines were sawn just above the condyle base, and fork lengths of the fish were also measured.

Otolith and first dorsal spine preparations

Among the 600 otoliths sampled from purse seiners and from longliners, a subsample of 178 pairs, were selected according to the size of the individuals. These otoliths were cleaned in bleach, rinsed with distilled water, then 90° alcohol and then dried. The right otolith was embedded, cut and prepared according to the method described by Secor *et al.* (1992) and adapted for tunas by Stéquert *et al.* (1996).

Whatever the size of the fish, the slice of otolith obtained by transverse section was attached with thermoplastic glue onto a piece of glass, itself attached onto a microscope slide. After polishing, when the nucleus was reached, the surface of the section was partially decalcified with EDTA (tri-sodium-ethylene-diaminetetraacetic acid, pH = 7.1). For the larger fish (> 100 cm FL), the piece of glass supporting the glued otolith slice was removed from the microscope slide and attached on a plot with a double face sticky-paper for observation under scanning electron microscope (SEM).

In the laboratory cross sections of the spines were prepared using a low-speed "ISOMET" saw. Sections were approximately 400-500 μm thick. These sections were observed in transmitted light (Fig. 1).

Age reading

For smaller bigeye (< 100 cm forklength (FL)), microincrements were counted on transverse sections under a light microscope (1000X) with a 100X dry objective (Fig. 2A). For larger fish (> 100 cm FL) counts were also realized under a light microscope and later on pictures using a scanning electron microscope at 2500 magnification. As for yellowfin tuna (Stéquert *et al*, 1996), counts were made along the external part of the transverse section, from the nucleus to the ventral edge (see D = D1 + D2 in Fig. 2B). Only 164 preparations were readable from the 178 selected, because some were broken during preparation (bad grinding or etc0hing) or presented some malformations. The daily periodicity of increment deposition on the sagittal otolith of bigeye tuna was demonstrated in the Pacific Ocean by IATTC (2001) and in the Atlantic Ocean by Hallier *et al.* (unpubl. data) by injection of oxytetracycline (Fig. 2C). We made the assumption that it should not be different in the Indian Ocean. Age in days was therefore estimated in this study by counting increments. For each of the 164 fish, three counts were made at different times, by the same reader, but without information concerning the size of fish or knowledge of the previous counts. The three counts were compared together with the coefficient of variation of Chang (1982) which is considered valuable if it is below 0.05 (Laine *et al.*, 1991). The fork length distribution of the 164 fish that had readable otoliths is shown in figure 3.

Several studies have shown that two rings are formed each year in dorsal spines. The first is a narrow translucent ring formed during the slower growth period. The second is a wide opaque ring formed during the fast growth period (Gaikov *et*

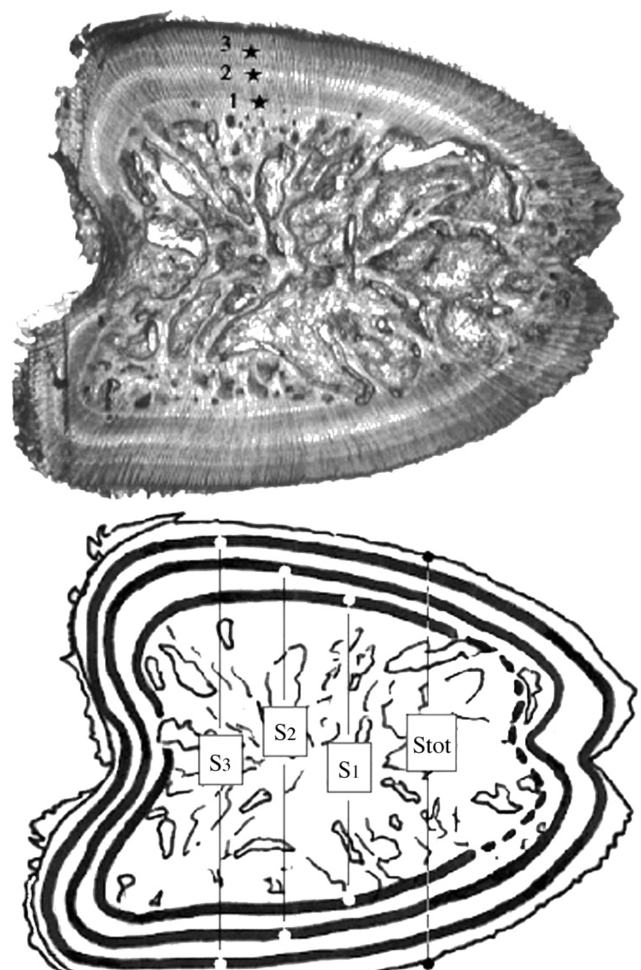

Figure 1. - Section of the first dorsal spine of a bigeye tuna with growth marks (stars 1, 2, 3) and surfaces measured: total surface (Stot) and surfaces (S1, S2, S3) included into rings.

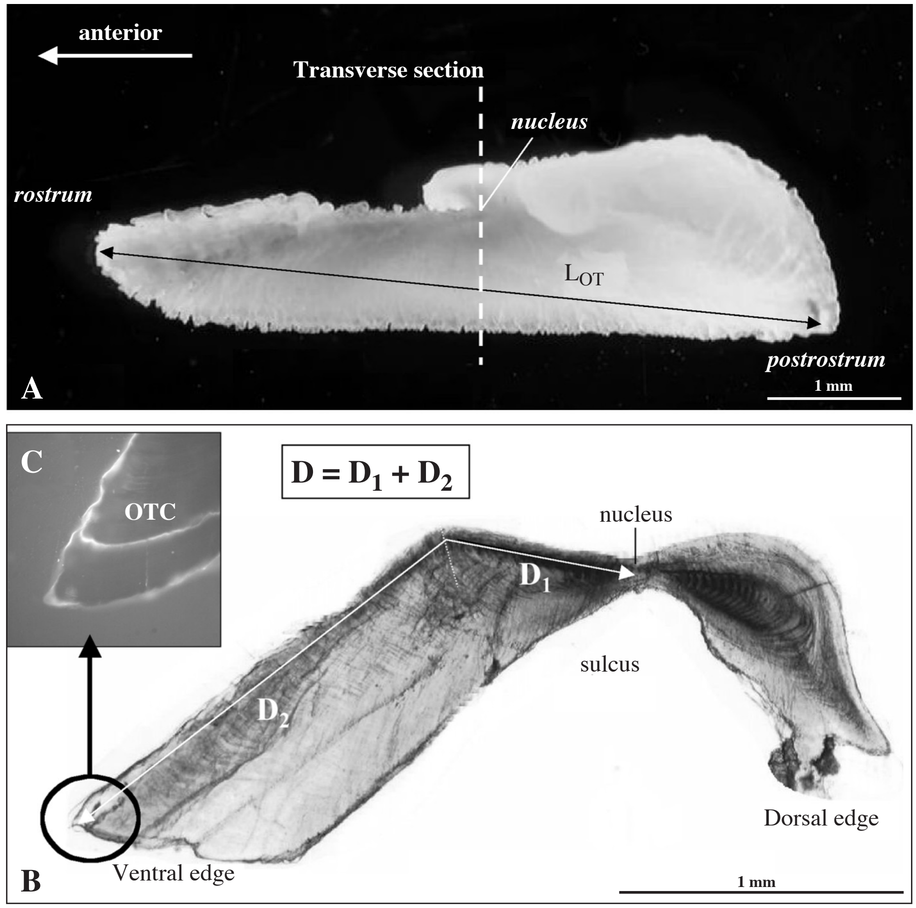

Figure 2. - **A**: Lateral view of the sagitta of a 98 cm FL bigeye tuna; LOT: length of otolith; **B**: Transverse section of an otolith from an oxytetracycline injected of a 104 cm FL bigeye tuna. D = D1 + D2: counting path of the microincrements; **C**: Detail of the oxytetracycline mark (OTC) (Hallier and Stéquert, unpubl. data).

al., 1980; Antoine *et al*., 1983; Sun *et al*., 2001). In a study of bigeye tuna growth in the North Western Pacific Ocean, Sun *et al*. (2001) showed that the narrow translucent rings of the dorsal spines were formed annually during the spawning season. The presence, however, of frequent doubtful or split translucent rings leads us to believe that counting was very subjective based on the decision whether to take a mark into account or not. Several studies point to the fact that some spines are impossible to interpret and that different readers interpret these differently. Furthermore, even when two readers reach agreement, the interpretation is still questionable. An additional difficulty is caused by the importance of the vascularized core of the spines resulting from the destruction of bone tissue. In this study, no counting of the rings were made and we chose to measure, for each spine: the total surface of the section, and the surface included into the translucent rings (Stot, S1, S2,… Sn). Surfaces were measured using an Image Analysis System (TNPC software). Only clear and obvious rings were measured and questionable ones were ignored. All measures of surfaces included into growth rings were pooled and a frequency distribution was made. We believe that modes observed on the studied tunas correspond to year of age. A relationship between the total surface of the section and the fork length was also established.

RESULTS

Relationships between otolith, dorsal spine and fork length

Inferring growth from changes in otoliths or dorsal spines requires the assumption that growth of the calcified structure of interest is proportional to body growth. We examined the relationship between fork length and two otolith dimensions. First was the length of otolith (LOT), measured along the anterior-posterior axis, from the rostrum to the postrostrum. Second was the length of the counting path (D) measured on the external part of the transverse section, from nucleus to the ventral edge (Fig. 2B). We established that the length of otolith (LOT) and the external part on transverse section (D) were directly proportional to the fork length of the fish, evidence that is consistent with the assumption described above. These relations are shown in figure 4:

$$L_{OT(cm)} = 0.007\ FL_{(cm)} + 0.5212, \text{ with } r^2 = 0.917$$
$$D_{(cm)} = 0.0016\ FL_{(cm)} + 0.085, \text{ with } r^2 = 0.907.$$

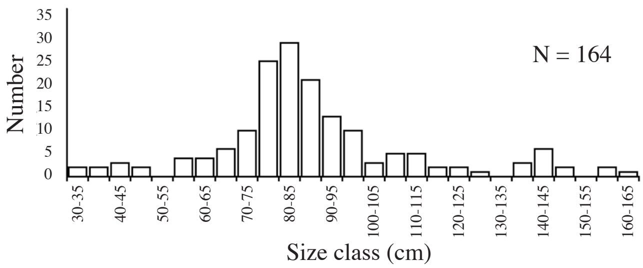

Figure 3. - Size distribution of bigeye tuna with readable otoliths.

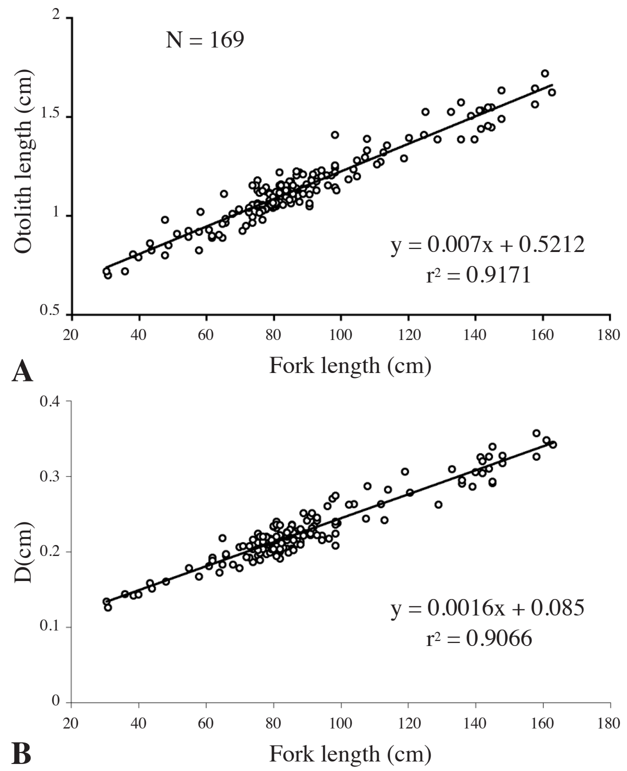

Figure 4. - Relationships between otolith sizes and fork length. **A**: Otolith length (LOT); **B**: Transverse section (D).

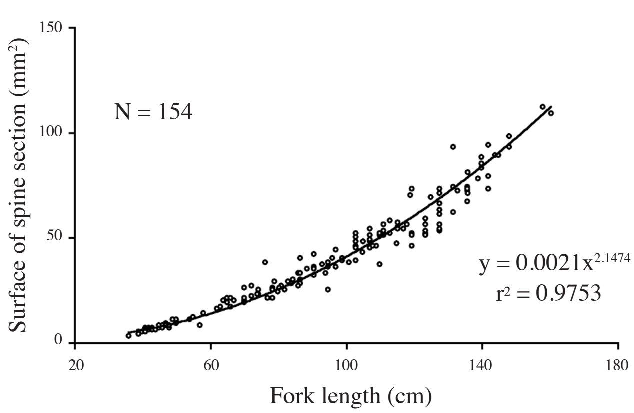

Figure 5. - Relationships between the surface of spine section and the fork length of bigeye tuna.

For the first dorsal spine, the relationship between the surface of the section and the fork length is presented in figure 5. Back calculation of the length of the fish for a measured surface of the ring is given by the equation:

$$FL_{(mm)} = 185.33 * S_{tot\ (mm^2)}^{0.4542}, \text{ with } r^2 = 0.9753$$

Age and growth

Otoliths

The use of a scanning electron microscope (SEM) allows us to understand the reason for the underestimation of the number of increments for larger fish when using an optical microscope, and thus the absolute necessity for using SEM when analysing microincrements. Hallier and Stéquert (unpubl. data) related the width of the microincrements to the distance from nucleus along axes D (Fig. 6A). After the metamorphosis of the early juvenile, the width decreases along the axis and thus during the growth of the fish. The width of the increment is about one micron at a distance of 2.5 to 3 mm. The relationship between the fork length of the bigeye tuna and the distance from nucleus (D) is presented in figure 6B. This clearly shows that for bigeye tunas over 120 cm, (D) is longer than 2.5 mm and, therefore, that the width of the microincrement is usually less than one micron.

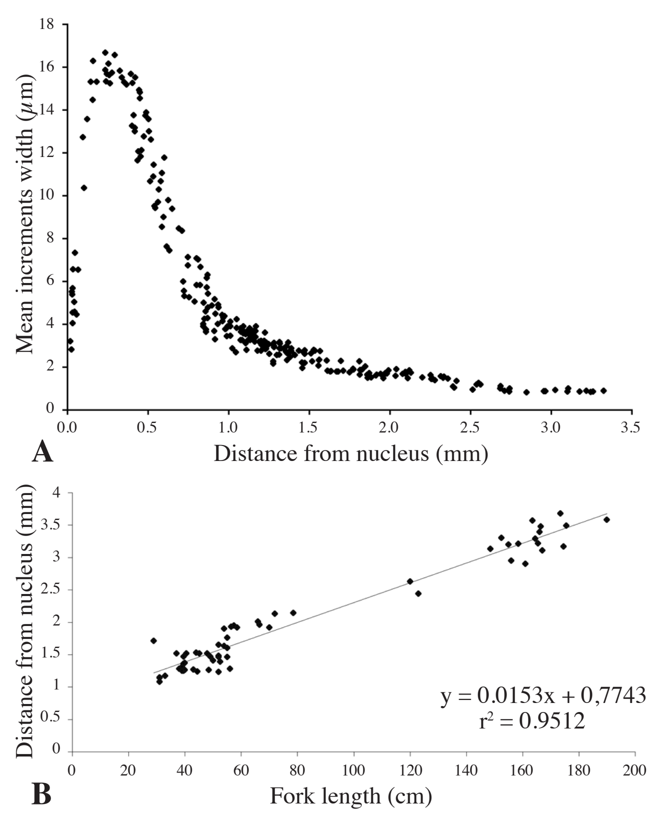

Figure 6. - Relationships between the mean increment width and the fork length (Hallier and Stéquert, unpubl. data). **A**: Relation of the mean increment width to the distance to nucleus; **B**: Relation between the distance from nucleus and the fork length.

The theoretical resolving power of optical microscope is 0.2 micron, but under one micron observation and counting of microincrements become very questionable. From this we infer that the use of SEM is definitively required for counting microincrements of bigeye tunas over 120 cm FL. Consequently, for this reason we decided to use the SEM for fish over 100 cm FL as a precaution.

Results of the counts are presented on figure 7. The mean CV (Chang, 1982) was 1.42%, which indicates that these counts are precise and reliable.

The estimates of the von Bertalanffy growth parameters were calculated using an iterative method generated by a non-linear regression analysis. For these calculations we used the software Statistica®. The parameters for the von Bertalanffy growth curves estimated in this study are given in table I, and table II presents the growth rates and sizes at different ages estimated with the model.

As the sex was not determined for the largest fish coming from the longliners, it was not possible to analyse whether any differences in growth occurred between males and females.

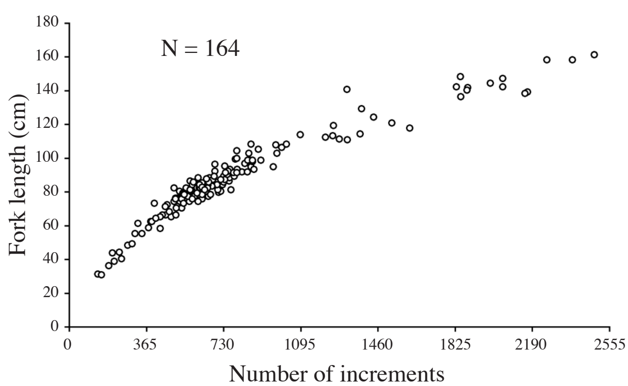

Figure 7. - Number of increments related to fork length observed on 164 bigeye tunas from the Indian Ocean.

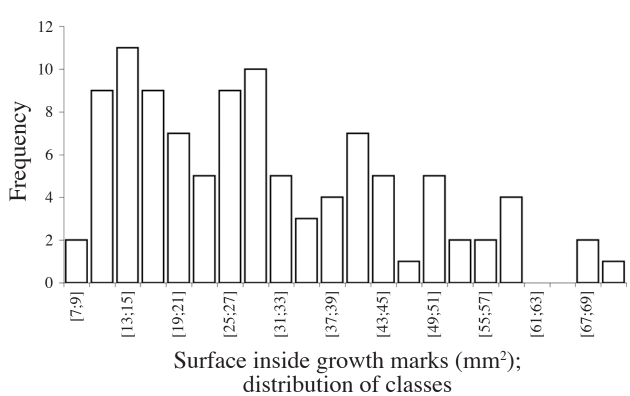

Figure 8. - Frequency distribution of surfaces included into growth marks observed on sections of dorsal spine.

First dorsal spine

The distribution frequency of the surfaces included into translucent growth rings is given by figure 8. Modes appeared to occur at 14 mm^2, 29 mm^2, 42 mm^2, which, using the back calculation, correspond to 61, 86 and 101 cm fork length respectively.

DISCUSSION

The various methods used by authors to determine age and growth of bigeye tuna from the tropical areas of the Pacific, Atlantic and Indian Oceans give rather different results (Tab. III). These variations could be explained by local and temporal biological variations but also by the different methods, technics and statistical procedures of researchers.

The study of growth, using size frequency analysis has long been the most frequently used method. Within the framework of population studies, the monitoring of a stock requires the regular sampling of landed fish and the measurement of a large number of individuals to determine the caught sizes. The logical continuation was to use all of these measurements to determine the growth parameters of the studied species. Concerning bigeye tuna, if the results obtained in the Eastern Atlantic by Marcille *et al*. (1978), Weber (1980) and Pereira (1984) are completely comparable, they are significantly different from those obtained previously in the Eastern Pacific by Kume and Joseph (1966). Thus, for example, for individuals from 3 to 4 years old, the differences in size are on average 20 to 30 cm. In the Indian Ocean, Marcille and Stéquert (1976) obtained a growth rate similar to those in the Atlantic, but only for young individuals (< 70 cm FL).

Thereafter, the spine of the first dorsal fin was preferred. Indeed, the use of dorsal spine to estimate age has the huge advantage of easy sampling, treatments and storage. This hard structure presents however, a major disadvantage. This is the vascularization of their core, involving sometimes the loss of the earlier growth mark. In spite of this problem, Gaikov *et al*. (1980), Draganik and Pelczarski (1984) and Delgado and Santana (1986) determined the growth parameters of the Atlantic bigeye tuna and more recently, Sun *et al*. (2001) calculated those in the Pacific. As for length frequency analysis, the results obtained using the first dorsal spine also present significant differences between the Atlantic, Pacific and Indian Ocean populations. For the Atlantic for example, we observed differences of 10 to 15 cm for one-year old individuals, and more than 30 cm for the 6-year old fish. Concerning this study, before using our method of surface distribution, several trials were made by counting the rings. However, we found that the interpretation of the reader was too important using this mehtod. This difficulty

	L_∞	S.E. on L_∞	k	S.E. on k	t_0	S.E. on t_0
VBGF parameters in cm and years	169.06	7.37	0.320	0.0037	-0.34	0.11
VBGF parameters in cm and days	168.99	7.37	0.000879	0.0001	-123.38	38.76

Table I. - Parameters of von Bertalanffy growth curve for western Indian Ocean bigeye tuna.

Table II. - Sizes and monthly growth rates at different ages of the Indian Ocean bigeye tuna, infered from the study of their otoliths.

Age (years)	Size (cm)	Growth rate (cm per month)
0.5 - 1	40 - 59	3.20
1 - 2	59 - 89	2.51
2 - 3	89 - 111	1.83
3 - 4	111 - 127	1.33
6 - 7	147 - 153	0.51

has been pointed out in several studies using tuna dorsal fin spines for studying growth (Antoine *et al*., 1983; Cayré and Diouf, 1983). The method finally used here avoid this bias. Our results are comparable with those of the Atlantic Ocean for young fish (1 and 2 years) but older fish have a lower growth rate (2.1 cm/month between 1 and 2 years decreasing to 1.25 cm/month between 2 and 3 years). The interpretation of the structures for fish over 3-year old was too questionable to use this method for larger individuals.

Several studies have been performed based on scales and vertebrae analysis: Yukinawa and Yabuta (1963) in the Pacific Ocean, Tankevich (1982) in the Indian Ocean and Alves *et al*. (2002) in the Atlantic. The results of these studies are generally not much different to those presented in this paper.

Cayré and Diouf (1984) for Atlantic Ocean and Hampton *et al*. (1998) for Pacific Ocean, studied the growth of bigeye tuna by using tagging experiments. Their results were highly different from each other (more than 30 cm for fish up to 4-year old) but those from Cayré and Diouf (1984) were not significantly different from those presented here.

Authors, Region, Method	Age 1	2	3	4	5	6
Stéquert and Conand (present study), Indian Ocean, otoliths	59	89	111	127	138	147
Stéquert and Conand (present study), Indian Ocean, spines	62	89	113	-	-	-
Stéquert and Conand (2000), Indian Ocean, otoliths	58	91	114	145	167	
Tankevich (1982), Indian Ocean, vertebrae and scales	63	83	99	115	130	145
Yukinawa and Yabuta (1963), Pacific Ocean, sizes distribution	44	76	102	123	140	-
Kume and Joseph (1963), Pacific Ocean, sizes distribution	44	76	102	123	140	-
Hampton *et al*. (1998), Pacific Ocean, otoliths and tagging	63	96	121	130	141	-
Sun *et al*. (2001), Pacific Ocean, spines	68	94	115	132	146	158
Lehodey *et al*. (1999), Pacific Ocean, otoliths and tagging	63	96	121	145	162	175
Clear *et al*. (2000), Pacific Ocean, otoliths	74	98	115	129	138	146
Marcille *et al*. (1978), Atlantic Ocean, sizes distribution	49	78	103	125	143	-
Gaikov *et al*. (1980), Atlantic Ocean, spines	46	79	107	130	150	166
Weber (1980), Atlantic Ocean, sizes distribution	49	72	94	115	135	154
Pereira (1984), Atlantic Ocean, sizes distribution	43	70	96	119	141	160
Cayré and Diouf (1984), Atlantic Ocean, tagging	44	70	93	114	132	148
Draganik and Pelczarski (1984), Atlantic Ocean, spines	44	80	109	131	149	164
Delgado and Santana (1986), Atlantic Ocean, spines	56	81	102	119	134	146
Alves *et al*. (2002), Atlantic Ocean, spines	48	73	94	116	133	146

Table III. - Comparison of results on growth studies of bigeye tuna in different oceanic regions and with different methods of investigation.

The otoliths were used for ageing in two different ways: annual increments or daily microincrements. Annual increments were counted on Pacific Ocean bigeye tunas by Clear *et al*. (2000) and their results were similar to our results. The count of daily growth increments with an optical microscope, performed by Lehodey *et al*. (1999) on bigeye tunas from the Pacific, and Stéquert and Conand (2000) from the Indian Ocean, also gave similar results with fast growth for large fish. These two studies were undertaken using only optical microscopy, which explain the strong underestimation of age and thus overestimation of growth after 3 or 4 years.

The few studies on bigeye tuna reproduction (Kume and Joseph, 1966; Calkins, 1980; Pereira, 1984; Hampton *et al*., 1998; Sun *et al*., 1999) estimate the size at first maturity near or slightly over 100 cm FL. This size is reached at the end of the second year of life. But, as pointed by Schaefer (2001), this value has to be considered with caution as it is influenced by differences in methodologies and also ecological variations.

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